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ABSTRACT

This report analyzes departmental variations in time to degree and attrition in Ph.D. programs at Berkeley. An alternative hypothesis, the Ph.D. production function, is examined by cross-section econometric analysis of 28 departments. The inputs included in the production function were student variables--quality and percent males; faculty variables--quality and number; and stipend support variables--number of T.A.'s, R.A.'s and fellowships. Estimates are given for the relative importance of each variable in explaining length of time to degree and attrition. The author argues that fellowships and research assistantships reflect the external market demand for Ph.D.'s, while teaching assistantships reflect the university's internal demand for instructional support. The production function and behavioral hypotheses are integrated by relating departmental differences in resources to an index of excess demand for Ph.D.'s by field. The author suggests that the production function hypothesis may be misleading, for increased resources unaccompanied by increased market demand may not lead to increased Ph.D. production. The paper concludes with an examination of the national production of new Ph.D.'s during the period 1947-1948 to 1967-68, focusing on Berkeley's relation to total supply. (Author)

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THE Ph.D. PRODUCTION FUNCTION:

THE CASE AT BERKELEY

David W. Breneman

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PREFACE

This is one of a continuing series of reports of the Ford Foundation sponsored Research Program in University Administration at the University of California, Berkeley. The guiding purpose of this Program is to undertake quantitative research which will assist university administrators and other individuals seriously concerned with the management of university systems both to understand the basic functions of their complex systems and to utilize effectively the tools of modern management in the allocation of educational resources.

This report is the second of three papers analyzing departmental variations in time to degree and attrition in 28 Ph.D. programs at the University of California at Berkeley. The first paper, "An Economic Theory of Ph.D. Production: The Case at Berkeley," developed a theory of departmental behavior to explain differences in performance. The present paper examines an alternative hypothesis, the Ph.D. production function while the third paper presents interview results and recommendations for university policy.

I. INTRODUCTION

Doctoral programs in the various disciplines differ markedly in both mean time to degree and in student attrition rates. A measure of the variation of student input to degree output in 28 fields at the University of California at Berkeley is provided in Table I, while data demonstrating similar patterns of variation at other universities is presented in Joseph Mooney's study of attrition rates in the Woodrow Wilson Fellowship program.[1] In a previous report published by the Ford Foundation Research Program in University Administration, a theory of departmental behavior was developed to explain these differences in performance.[2] Academic departments were assumed to be engaged in prestige maximizing behavior, which reduced operationally to maximizing control over university resources and securing satisfactory placement for doctoral students. Since university resources are often linked to enrollments, departments were viewed as desiring large graduate enrollments, while determining the number of Ph.D. degrees to award according to the perceived demand for graduates in each field. Control variables that allow departments to regulate supply include curriculum organization, performance standards, dissertation requirements, allocation of financial support, information flows to students, and faculty effort.

An alternative explanatory hypothesis to this behavioral theory is the production function approach. In this view, variations in departmental performance are "explained" by variations in resource inputs, with the

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[1]Joseph Mooney, "Attrition among Ph.D. Candidates: An Analysis of a Cohort of Recent Woodrow Wilson Fellows," Journal of Human Resources, Winter 1968.

[2]David Breneman, "An Economic Theory of Ph.D. Production: The Case at Berkeley," Ford Foundation Research Program, Office of the Vice President, Planning and Analysis, Berkeley, June 1970. The reader should refer to this paper for a detailed statement of the behavioral theory.

TABLE I: SEVEN YEAR ENROLLMENT AND DEGREE TOTALS, UNIVERSITY OF CALIFORNIA, BERKELEY, 1961-67*

DEPARTMENT	*Column A* Ph.D. Degrees Awarded	*Column B* Ph.D. Student Years[a]	Degrees per Student Year (Col A/Col B)	Student Years per Degree (Col B/Col A)
Entomology	79	397	.198	5.02
Chemistry	335	1802	.185	5.38
Chemical Engin.	75	404	.185	5.39
Electrical Engin.	175	1032	.169	5.90
Civil Engin.	129	763	.169	5.91
Physics	380	2438	.155	6.42
Zoology	94	634	.148	6.74
Botany	52	352	.147	6.77
Geology	37	270	.137	7.30
Biochemistry	63	469	.134	7.44
Geography	21	158	.132	7.52
Mechanical Engin.	94	716	.131	7.62
Psychology	162	1238	.130	7.64
Astronomy	32	246	.130	7.69
Spanish	18	150	.120	8.33
History	177	1517	.116	8.57
Mathematics	194	1680	.115	8.66
Classics	13	118	.110	9.08
German	24	219	.109	9.12
Bacteriology	17	157	.108	9.24
Economics	137	1316	.104	9.61
Anthropology	69	720	.095	10.43
Political Science	96	1026	.093	10.69
Physiology	24	267	.089	11.12
English	105	1374	.076	13.09
Sociology	57	753	.075	13.21
French	28	374	.074	13.36
Philosophy	27	507	.053	18.78

[a] Enrollment figures are understated for those departments that require doctoral students to first earn the M.A. degree - those student years are not recorded. Enrollments include both degree and non-degree winners.

*Source: Office of Institutional Research, University of California, Berkeley.

implication that if all departments are given equal resources, the extremes of performance variation documented in Table I will be eliminated.

In the present paper, the production function hypothesis is examined by cross-section econometric analysis of 28 departments at the University of California at Berkeley. Following the regression results, the production function and behavioral hypotheses are integrated by relating departmental differences in resources to an index of excess demand for Ph.D.'s by field. The paper concludes with an examination of the national production of new Ph.D.'s during the period 1947-48 to 1967-68, focusing upon Berkeley's relation to total supply. It is argued that analysis of the supply side further strengthens the behavioral, demand-oriented hypothesis.

II. THE Ph.D. PRODUCTION FUNCTION

We have noted that several authors argue that departmental differences in Ph.D. success rates can be explained by variations in financial support available to graduate students in the various disciplines. Although not explicitly stated, this view assumes the existence of an underlying Ph.D. production function, with output variation caused by input variation. External factors, such as the job market, or internal factors, such as departmental objectives, play no role in this hypothesis. Furthermore, if one believes that a Ph.D. production function exists, and if one wants to equalize departmental performance, then the obvious policy prescription is simply to equalize inputs. An implicit belief of this type seems to have motivated the Ford Foundation Career Fellowship Program which is currently providing financial support for graduate students in eight traditionally "under-supported" humanities and social science disciplines. Systematic examination of the production function hypothesis has not been attempted in previous work on this topic; because of the importance of the hypothesis from a policy perspective, this is a serious omission. Consequently, in this chapter we will assume that a Ph.D. production function does exist, and attempt to estimate parameters by cross-section econometric analysis of 28 Berkeley departments. At the close of this chapter, we shall discuss the relation of the production function hypothesis to the theory of departmental behavior discussed earlier.

The resources required to produce Ph.D.'s are easily enumerated; the necessary inputs include:

(1) graduate students
(2) faculty

(3) financial support for graduate students
(4) capital goods such as classrooms, libraries, computer centers, and laboratories.

Furthermore, each of the inputs can be characterized by a variety of quantitative and qualitative attributes in the following manner:

(1) Student input

(a) Academic quality of the graduate students, as measured by undergraduate performance, GRE scores, or some other criterion
(b) the percentage of male students
(c) the percentage of married students
(d) the percentage of foreign students
(e) a variety of other descriptive attributes by which people are differentiated;

(2) Faculty input

(a) academic quality of the faculty input, as measured by reputation of the department, publications, or some other criterion
(b) categorization by rank, i.e., percent full, associate, and assistant professors, and percent instructors, lecturers, associates;

(3) Stipend support

(a) percent employed as Teaching Assistants (T.A.'s)
(b) percent employed as Research Assistants (R.A.'s)
(c) percent on fellowship
(d) percent self-financed;

(4) Capital equipment

(a) libraries
(b) laboratories
(c) computer center
(d) funds for field research.

Given the variety of possible input characterizations, several simplifications must be introduced prior to econometric work. Since the production function is to be estimated by cross-section regressions over 28 departments, variables must be excluded that are not comparable across disciplines. This suggests that the first necessary simplification is the elimination of capital equipment variables from the production function. Since the different disciplines do not require the same types of capital inputs, physical units of capital cannot be used. Unfortunately, dollar values are not available for most capital goods. However, it is fair to assume that at Berkeley the particular capital requirements of each field are present in the amounts required for Ph.D. production; humanities students have excellent libraries, science students have computer centers and research laboratories. Thus, eliminating capital equipment should not seriously affect our attempt to test whether the imbalance of comparable resources explains differences in departmental performance.

We are left, then, with three basic inputs - students, faculty, and financial support - which can be compared across disciplines. Furthermore, the production function approach involves the assumption that time to degree can be the same in all fields and that nothing in the technology dictates the extremes of attrition noted earlier. The latter point seems self-evident, and in support of the former, we quote Berleson:

> In recent years, as part of the concern with the "Ph.D. stretch-out," there have been several calls, notably by the 1957 committee of AGS deans, to set a clear norm for how long it should take to get the doctoral degree. The norm proposed is usually three or four years, and on this point everyone seems to agree...In short, the norm proposed is almost exactly what it now *does take*, in full-time equivalence. Hence, when people call for the establishment of a norm for the duration of doctoral work for the full-time qualified student, they should know that it is here: it is agreed upon, probably as well as

anything in academic life, and it is being realized in practice.[3]

With regard to the qualitative distinctions characterizing inputs mentioned above, the following seem to capture the most important factors to be included in the production function:

(1) Students
  (a) quality
  (b) percent male
(2) Faculty
  (a) quality
  (b) number of full, associate, and assistant professors
(3) Stipend support
  (a) number of teaching assistantships
  (b) number of research assistantships
  (c) number of fellowships, $2,000 or more.

The rationale for including these variables may be noted briefly. The quality of the students enrolled in each field is an important factor, since better students should be able to complete degree work more rapidly than poor students. Variations among departments in the percent of male graduate students must also be considered, not because we believe this distinction <u>should</u> make a difference, but simply because both the Stark and Mooney studies found that female graduate students have a lower success rate than males regardless of field. One purpose of this chapter is to test whether this distinction is in fact important. Other possible descriptive factors such as percent married or percent foreign did not display sufficient systematic variation to render their inclusion worth the cost in lost degrees of freedom.

With regard to faculty, in addition to a measure of quality, we exclude all non-professorial ranks since lecturers, instructors and associates rarely are involved in Ph.D. production, particularly at the dissertation stage.

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[3] Bernard Berelson, <u>Graduate Education in the United States</u>, McGraw-Hill, 1960, pp. 161-162.

Thus, we include as faculty input the number of Full Time Equivalent (FTE) assistant, associate and full professors in a department, with no distinction regarding rank, since in most departments all three groups participate in doctoral education.

The three most prevalent methods of providing financial support for graduate students are the teaching assistantship (T.A.), the research assistantship (R.A.), and the fellowship. Since the first two require some form of work, while the third is a pure award, we want to examine the relative impact of each method of funding. Thus we include the number of T.A. and R.A. positions and the number of fellowships available to students in each department. In order to keep the dollar amount commensurable, only fellowships of $2,000 or more are considered.

Of the variables discussed, the student and faculty quality measures pose severe operational problems of definition. Particularly difficult is the specification of a measure which meaningfully compares the quality of graduate students enrolled in such diverse fields as physics and English. Operating across disciplines, it is by no means clear how one would interpret measures such as GRE scores, for example. Furthermore, data on average GRE scores by department were not available. Instead, as a single measure for both student and faculty quality, each department's Cartter Report[4] ranking was used. With respect to faculty, the Cartter rankings need minimal justification since the report was designed to measure faculty quality. The argument for using this variable to render the quality of student input comparable across fields is based upon the assumption that, in each discipline, the best students nationally will be found in the best departments as ranked

[4] Cartter, Allan, "An Assessment of Quality in Graduate Education," American Council on Education, Washington D.C., 1966.

by the Cartter Report. Thus, if two departments at Berkeley carry the same national ranking, it is assumed that relative to their disciplines, the departments will have comparably qualified students.

It should be noted that this approach assumes that the quality rating of faculty will be matched by the quality of the students, i.e., the best faculty will attract the best students. If this is a reasonable assumption, then we no longer have two separable quality measures, one for students and one for faculty, but instead one measure for the quality of the department. Thus, inclusion of the Cartter ranking in the regression will allow us to test whether variations in departmental quality are systematically related to differences in departmental "efficiency." We would like to know whether an increase in a department's national ranking with the implied ability to attract better students will improve the department's performance in Ph.D. production. In fact, the range of rankings for the 28 Berkeley departments included is not great, the lowest national ranking being sixth. One might argue that such uniformly high rankings implies that we are studying a relatively high quality group of graduate students; however, the spread from ranking first to sixth may encompass a significant difference in the quality of student input, thereby affecting departmental performance.

We now write our production function as follows:

$$PhD_i = f(PHEN_i, FAC_i, NUMTA_i, NUMRA_i, NUMAW_i, NUMALE_i, CARTRK_i) \quad (A)$$

where:

PhD_i = number of Ph.D.'s produced in department i

$PHEN_i$ = number of Ph.D. students enrolled in department i

FAC_i = number of FTE professors in department i

$NUMTA_i$ = number of T.A. positions in department i

$NUMRA_i$ = number of R.A. positions in department i

$NUMAW_i$ = number of fellowships in department i

$NUMALE_i$ = number of male Ph.D. students in department i

$CARTRK_i$ = the Cartter Report ranking of department i .

Equation (A) is altered by dividing all variables (except the Cartter ranking) by $PHEN_i$ to produce a functional form more likely to have constant error variance. The new system becomes:

$$\frac{PhD_i}{PHEN_i} = g\left\{\frac{FAC_i}{PHEN_i}, \frac{NUMTA_i}{PHEN_i}, \frac{NUMRA_i}{PHEN_i}, \frac{NUMAW_i}{PHEN_i}, \frac{NUMALE_i}{PHEN_i}, CARTRK_i\right\}. \quad (B)$$

Meaningful estimation of equation (B) is not possible, however, because of the impossibility of separating the necessary data on Ph.D. programs from the data on M.A. programs.[5] Discussions with graduate secretaries in all 28 departments made it apparent that efforts in that direction were doomed to failure. Precise data on Ph.D. enrollments that excluded terminal M.A. students could not be gathered, nor could one assume that departments allocate their T.A., R.A., and fellowship awards solely to Ph.D. students. Thus, an estimation technique that incorporated the M.A. as a second output was required.

The problem was solved in the following manner. If we eliminate from our data M.A. degrees that are awarded to Ph.D. candidates en route to the doctorate, we can then view each department as producing terminal M.A.'s and Ph.D.'s as alternative outputs. It is hypothesized that a product transformation curve exists between the two degrees as in Figure 1. The figure simply suggests that, with double counting of degrees eliminated, a trade-off exists between terminal M.A. and Ph.D. degrees. Every Ph.D. produced is at the expense of terminal M.A. output, and vice versa. Thus, our data will support estimation of the following model:

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[5]See Breneman, D. W., "An Economic Theory of Ph.D. Production: The Case at Berkeley," Ford Foundation Research Program in University Administration, Paper P-8, University of California, Berkeley, 1970.

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$$PhD_i + MA_i = h(GREN_i\ ,\ FAC_i\ ,\ NUMTA_i\ ,\ NUMRA_i\ ,\ NUMAW_i\ ,\ NUMALE_i\ ,\ CARTRK_i) \qquad (C)$$

where the new variables are defined as:

MA_i = number of terminal M.A. degrees produced by department i

$GREN_i$ = total graduate enrollment in department i .

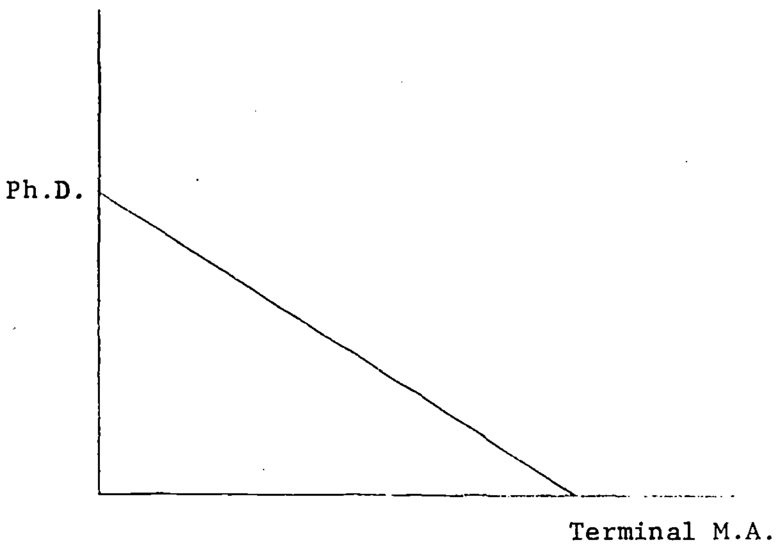

Figure 1

Dividing both sides by $GREN_i$, moving the term $\frac{MA_i}{GREN_i}$ to the right side, and assuming the variables enter linearly renders the following linear regression model to be estimated:

$$\frac{PhD_i}{GREN_i} = \beta_o + \beta_1 \frac{MA_i}{GREN_i} + \beta_2 \frac{FAC_i}{GREN_i} + \beta_3 \frac{NUMTA_i}{GREN_i} + \beta_4 \frac{NUMRA_i}{GREN_i}$$

$$+ \beta_5 \frac{NUMAW_i}{GREN_i} + \beta_6 \frac{NUMALE_i}{GREN_i} + \beta_7\ CARTRK_i + \mu_i\ . \qquad (D)$$

A priori, we would expect coefficients β_1 and β_7 to be negative, the rest to be positive. β_1 should be negative by the logic of the product transformation curve, while β_7 should be negative since, by hypothesis, quality is inversely related to the numerical ranking of departments, i.e., number one is higher than number six. β_2, the coefficient of the faculty-student ratio, should be positive if one believes that a larger faculty input per student will save student time or reduce attrition. However, if our analysis of the budgeting process is correct,[6] large systematic variations in the faculty-student ratio across departments should not exist; this suggests that β_2 will be measured imprecisely. The coefficients of the financial support variables, β_3, β_4, and β_5 should all be positive, but of different magnitude. β_3 should have the smallest impact since work as a T.A. is not directly related to degree progress; the relative magnitudes of β_4 and β_5 cannot be determined *a priori* since fellowships allow full time study, but research assistantships often lead directly to a dissertation. Finally, β_6 should be positive if it is true that men are generally more successful in earning Ph.D.'s than women.

Since degree figures for a single year may be unrepresentative, M.A. and Ph.D. degrees for the four year period, 1964-67, were collected, while four year graduate enrollments covering the 1963-66 and 1962-65 periods were used, introducing alternatively a one or two year lag in the flow-stock ratio. Results for both sets of enrollment data will be reported; the estimates were generally not highly sensitive to the particular lag involved. Faculty figures represented a similar multiple year average, while data on teaching assistantships, research assistantships, and fellowships came from a Berkeley Office of Institutional Research survey,[7] completed in the Spring of 1966-67 academic year. The proportion of male students came directly from the enroll-

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[6] See Breneman, op. cit., for this analysis.

[7] Sidney Suslow, Roger Hamilton, Norma Goorvitch, Student Financial Support Berkeley, Office of Institutional Research, Berkeley, University of California, 1968.

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ment series, while the quality rankings appear in the 1966 Cartter Report based on survey data collected in 1964.

Table II reports the regression results. Ten equations are reported, numbers 1 to 5 based on the one year lag in the flow-stock ratio, equations 6 to 10 based on the two year lag. Thus, sensitivity of results to the particular lag can be seen by comparing equation 1 with 6, 2 with 7, and so forth. Estimates of the full model (equation (D), page 11 in the text) are reported as equations 4 and 9. In addition, a composite variable, NUMFIN , is introduced in regressions 2, 5, 7, and 10. The acronym stands for "number financed," since NUMFIN ≡ NUMTA + NUMRA + NUMAW ; this v riable was included to allow us to test whether the form of financial support (T.A., R.A., or award) makes any difference in Ph.D. production.

The analysis shall be limited to the one year lag model, equations 1 to 5, except for an occasional comment regarding differences between parameter estimates in the one and two year lag structures. Looking first at equation 4, we note that the signs of the coefficients are as predicted, i.e., all are positive except for β_1 and β_7 , the coefficients for M.A. degrees and Cartter Report rankings. Were we interested in testing for each variable the hypothesis that its coefficient is zero, we would, at the 95% confidence level, reject the hypothesis only for the number of terminal M.A.'s, R.A.'s, and awards. Such hypothesis tests may be of little interest in the present context; however, a few words regarding the various coefficient estimates are in order.

The estimated coefficient of our transformation line between Ph.D.'s and terminal M.A.'s in equation 4 is -.201. This states simply that departments can trade terminal M.A.'s and Ph.D.'s in the ratio of five to one,

TABLE II

ESTIMATES OF THE Ph.D. PRODUCTION FUNCTION

Dependent Variables $\frac{PhD}{GREN}$

Equation No.	Independent Variables									R^2
	Constant	$\frac{MA}{GREN}$	$\frac{FAC}{GREN}$	$\frac{NUMTA}{GREN}$	$\frac{NUMRA}{GREN}$	$\frac{NUMAW}{GREN}$	$\frac{NUMFIN}{GREN}$[b]	CARTRK	$\frac{NUMALE}{GREN}$	
	ONE YEAR LAG[a]									
1	.049 (.020)	-.175 (.052)	.025 (.048)	.028 (.035)	.165 (.028)	.094 (.033)				.812
2	.032 (.026)	-.183 (.066)	-.038 (.059)				.135 (.029)			.663
3	.066 (.025)	-.179 (.051)	.021 (.048)	.013 (.036)	.162 (.027)	.076 (.036)		-.003 (.0025)		.825
4	.025 (.035)	-.201 (.051)	.016 (.046)	.049 (.042)	.131 (.033)	.097 (.037)		-.003 (.0024)	.048 (.030)	.845
5	-.012 (.025)	-.217 (.051)	-.004 (.046)				.110 (.024)	-.002 (.0024)	.084 (.019)	.819

(Continued on next page)

[a] Degrees awarded 1964-67, graduate enrollments 1963-66.

[b] NUMFIN = NUMTA + NUMRA + NUMAW, i.e., the total number financed by all three sources.

TABLE II (Continued)

Equation No.	Independent Variables									R^2
	Constant	MA/GREN	FAC/GREN	NUMTA/GREN	NUMRA/GREN	NUMAW/GREN	NUMFIN/GREN	CARTRK	NUMALE/GREN	
	TWO YEAR LAG[c]									
6	.057 (.022)	-.160 (.053)	.055 (.052)	-.055 (.038)	.170 (.029)	.067 (.036)				.790
7	.031 (.030)	-.150 (.073)	-.023 (.068)				.131 (.034)			.559
8	.076 (.027)	-.165 (.053)	.052 (.051)	-.022 (.040)	.167 (.029)	.048 (.039)		-.003 (.0027)		.804
9	.036 (.038)	-.186 (.053)	.047 (.050)	.012 (.046)	.137 (.035)	.067 (.040)		-.003 (.0026)	.046 (.032)	.822
10	-.022 (.028)	-.206 (.056)	.020 (.052)				.100 (.027)	-.002 (.0027)	.101 (.022)	.755

[c]Degrees awarded 1964-67, graduate enrollments 1962-65.

i.e., five M.A.'s are estimated to be the equivalent of one Ph.D. This ratio becomes critical in our later evaluation of relative departmental performance.

Faculty input, as measured by the faculty-graduate student ratio, does not display the systematic variation across departments that would allow its coefficient to be precisely measured. For example, both the English and Chemistry departments have graduate student-faculty ratios of approximately 8 to 1, which coincides with the weighted student-faculty ratio agreed upon with the State Department of Finance. This constancy of the student-faculty ratio is consistent with our analysis of internal resource allocation, and suggests that variations in departmental "efficiency" cannot be explained by imbalances in faculty staffing. Furthermore, on the basis of the estimated coefficient, 0.16, we should not expect the marginal impact on Ph.D. production of an additional professor to be very large. We can demonstrate this by considering the limited impact on Ph.D. production estimated for a very large increase in faculty input. The mean value of the independent variable $\left(\frac{FAC}{GREN}\right)$ is .155; doubling faculty input would increase this variable by .155 to .310. The estimated increase in the mean value of the dependent variable $\left(\frac{PhD}{GREN}\right)$ would be $(.155)(.016) \simeq .003$. The mean value of the dependent variable is .094, representing an output of less than one-tenth Ph.D. per student year; doubling the faculty would increase this variable to .097, an insignificant change. Of course, a qualitative improvement of considerable magnitude might result from increased faculty numbers, but our estimates suggest that we should not expect much increase in the number of Ph.D.'s produced.

The small coefficient and large standard error of the T.A. variable highlight the countervailing tendencies present in that form of financing graduate work. Presumably, it is more pleasant for a graduate English student to

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finance his studies by work as a T.A. than by part-time work at the Post Office; however, it is not clear that the two types of work differ appreciably in their impact on the student's ultimate success in earning the Ph.D. The large number of T.A. positions in the French department, for example, may have the effect of providing the large graduate enrollment which, when measured against hte department's output of 2-3 Ph.D.'s annually, produces the department's low "efficiency" rating. It is conceivable that eliminating several T.A. positions would reduce the graduate enrollment in French but not affect the Ph.D. output, thereby improving the department's performance. We note that in two of the regressions (equations 6 and 8) the T.A. variable actually enters with a negative coefficient.

If we accept the estimate of the T.A. coefficient in equation 4, we would predict that an increase of more than 50% in the number of T.A. positions (mean value of $\frac{NUMTA}{GREN}$ rising from .192 to .292), would increase the dependent variable by $(.1)(.049) \simeq .005$ Ph.D.'s per student year. Thus, the mean value of our left hand variable would increase from .094 to .099 Ph.D.'s per student year, a reduction of student input per degree from 10.6 years to 10.1 years. Based on the data available, the 50% increase in the number of students employed as T.A.'s in these 28 departments would require approximately 360 new T.A. positions. Given 1966-67 financing, the 28 departments produced an annual average of 450 Ph.D. degrees with a graduate enrollment of approximately 4790; our estimate suggests that the 360 new T.A. positions would increase the number of Ph.D.'s awarded annually to 474, a gain of 24 Ph.D.'s per year. The subtleties of cost-benefit analysis would be required to determine whether additional Ph.D.'s are worth the cost of 15 new T.A. positions each; however, this numerical excursion does suggest that securing additional teaching assistantships is not a very effective way to increase Ph.D. production.

The estimated coefficients on the R.A., T.A., and award variable indicate that the most effective method of financing graduate work is the research assistantship, followed by fellowship support, with teaching assistantships a poor third. This finding confirms the views of several Berkeley professors,[8] who have commented upon the value of research assistantships in providing research training and dissertation topics. These professors noted that fellowship students do well in course work, but often experience great difficulty in getting started on the dissertation. In addition, fellowship students may have failed to gain the close faculty contact and practical research techniques that often accrue to the student R.A.

The coefficient of the Cartter Report ranking is estimated at -.003, with large standard error. This suggests that the variation of quality represented by these 28 Berkeley departments is not great, although a shift from sixth ranking to first ranking would produce an estimated increase of (-5)(-.003) = .015 Ph.D.'s per student year. Note that this increase is three times the magnitude attributed to a 50% increase in the proportion of students serving as T.A.'s, which suggests that quality is not a trivial factor relative to financial support.

Analysis of the proportion male variable $\left(\frac{NUMALE}{GREN}\right)$ will be deferred to a later paragraph, for interpretation of this variable requires examination of its interacting effects with other variables. For the moment, we simply note that its coefficient is positive but measured imprecisely.

Before proceeding to analysis of residuals, a few brief comments on the other regression models should be made. Equation 1 represents a simplified model with the qualitative variables CARTRK and $\frac{NUMALE}{GREN}$ excluded. This model assumes that student input should not be qualified in any manner,

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[8] Expressed to the author in private conversations.

i.e., females enrolled in a sixth ranked department are the equivalent of males enrolled in a first ranked department. Contrasting this model to that estimated in equation 4, we see that in equation 1 the coefficient for R.A.'s is increased while that for T.A.'s is reduced. In addition, the M.A. - Ph.D. trading ratio is reduced to .175.

In equation 2, the three financial support variables are combined into a single variable measuring the proportion financed. We wish to test the hypothesis that only the proportion financed matters, not the method of financing. The test is accomplished by considering the following model:

$$\text{Ph.D.} = \beta_o + \beta_1 \frac{\text{MA}}{\text{GREN}} + \beta_2 \frac{\text{FAC}}{\text{GREN}} + \beta_3 \frac{\text{NUMTA}}{\text{GREN}} + \beta_4 \frac{\text{NUMRA}}{\text{GREN}} + \beta_5 \frac{\text{NUMAW}}{\text{GREN}} + \mu \,. \qquad \text{(E)}$$

The hypothesis that only financing matters, not the method, implies that $\beta_3 = \beta_4 = \beta_5$, in which case one could estimate alternatively the following model:

$$\frac{\text{PhD}}{\text{GREN}} = \beta_o' + \beta_1' \frac{\text{MA}}{\text{GREN}} + \beta_2' \frac{\text{FAC}}{\text{GREN}} + \beta_3' \left[\frac{\text{NUMTA} + \text{NUMRA} + \text{NUMAW}}{\text{GREN}}\right] + \mu' \,. \qquad \text{(F)}$$

Since NUMFIN $\equiv$ NUMTA + NUMRA + NUMAW, equation 2 in Table II represents the estimation of the above model. Using an F statistic, we tested the hypothesis that $\beta_3 = \beta_4 = \beta_5$; at the 99% confidence level, the hypothesis is rejected. Thus, the method by which graduate work is financed does appear to make a difference in student success.

In equation 5, the composite variable NUMFIN is introduced in the context of the full model; the above hypothesis was tested again, but this time could not be rejected. The difference is explained by the inclusion of the $\frac{\text{NUMALE}}{\text{GREN}}$ variable in equation 5, and leads us to consider the interaction between the proportion of male students and the financial support variables.

The proportion of male students is positively correlated with the R.A.

variable and negatively correlated with the T.A. variable. The largest number of R.A.'s are found in the physical sciences and engineering disciplines, fields with a high proportion of male students, while large numbers of T.A.'s are found in the humanities, where the proportion of men is lower. Thus, in regression equation 5, lumping the financial variables together allows the $\frac{\text{NUMALE}}{\text{GREN}}$ variable to act as a proxy for some of the differential financing effect, the coefficient estimate increasing from .048 in equation 4 to .084 . Similarly, in equation 1 where proportion male is excluded, the financial variables pick up some of the effect of the excluded variable. Therefore, if we believe that sex in itself makes a difference in Ph.D. performance, then we conclude that the type of financing is probably not important. If we reject the view that sex matters, then it appears that the method of financing is important. Due to high collinearity, we cannot distinguish between these two possibilities.

If we truly believe in the existence of a Ph.D. production function, and if we believe that the model has been accurately and fully specified, then examination of residuals will indicate which departments are operating at greater than average efficiency and which at less than average efficiency. Table II, columns one and two, contains the actual and fitted values of the dependent variables (Ph.D.'s awarded divided by total graduate enrollment) from regression equation 4, Table II. In the third and fourth columns of Table II the reciprocals of the actual and fitted values of the dependent variables are presented; these values represent the number of enrolled graduate student years per Ph.D. awarded in each department. We remind the reader that the enrollment figures include both M.A. and Ph.D. students and that the fitted values have been based upon the estimate that five terminal M.A. degrees are the equivalent of one Ph.D. degree. No distinction has been made between a terminal Masters' degree earned and desired by an Electrical

TABLE III: RESIDUALS FROM REGRESSION EQUATION 4, TABLE II

Department	*Col. 1* Actual Value, PhD/GREN	*Col. 2* Fitted Value, PhD/GREN	*Col. 3* Actual Value, GREN/PhD	*Col. 4* Fitted Value GREN/PhD	*Col. 4* Minus *Col. 3*
Classics	.0866	.0824	11.55	12.14	+ 0.59
English	.0389	.0423	25.71	23.64	- 2.07
French	.0465	.0343	21.51	29.15	+ 7.64
German	.0518	.0521	19.31	19.19	- 0.12
Philosophy	.0533	.0678	18.76	14.75	- 4.01
Spanish	.0410	.0497	24.39	20.12	- 4.27
Anthropology	.0948	.0925	10.55	10.81	+ 0.26
Economics	.0884	.0653	11.31	15.31	+ 4.00
Geography	.0717	.0662	13.95	15.11	+ 1.16
History	.0732	.0653	13.66	15.31	+ 1.65
Political Science	.0715	.0872	13.99	11.47	- 2.52
Sociology	.0510	.1035	19.61	9.66	- 9.95
Bacteriology	.0929	.0845	10.76	11.83	+ 1.07
Biochemistry	.1522	.1504	6.57	6.65	+ 0.08
Botany	.1375	.1238	7.27	8.08	+ 0.81
Entomology	.1531	.1331	6.53	7.51	+ 0.98
Physiology	.0755	.0928	13.25	10.78	- 2.47
Psychology	.1248	.1213	8.01	8.24	+ 0.23
Zoology	.1109	.1080	9.02	9.26	+ 0.24
Astronomy	.1361	.1231	7.35	8.12	+ 0.77
Chemistry	.1696	.1578	5.90	6.34	+ 0.44
Geology	.1133	.1207	8.83	8.29	- 0.54
Mathematics	.1062	.1038	9.42	9.63	+ 0.21
Physics	.1539	.1631	6.50	6.13	- 0.37
Chemical Engineering	.1014	.1158	9.86	8.64	- 1.22
Civil Engineering	.0899	.0834	11.12	11.99	+ 0.87
Electrical Engineering	.0913	.0882	10.95	11.34	+ 0.39
Mechanical Engineering	.0751	.0732	13.32	13.66	+ 0.34

Engineering student and a consolation prize M.A. awarded to an unsuccessful Ph.D. candidate in French; both types of M.A. have been treated as equally valuable. The final column in Table III was computed by subtracting column three from column four, fitted minus actual values. If we accept all of the underlying assumptions, then a positive entry in column five indicates an efficient department, a negative entry an inefficient department, with the numerical values representing the number of student years per Ph.D. degree "economized" by efficient departments or "wasted" by inefficient departments. We note that the departments of English, Philosophy, Spanish, Political Science, Sociology, Physiology, and Chemical Engineering, absorbed one or more student years per Ph.D. degree in excess of their fitted regression values, while the departments of French, Economics, Georgraphy, History, and Bacteriology, utilized one or more student years less per Ph.D. degree than their fitted values.

In order to demonstrate the relative importance of the several independent variables, Table IV contains a detailed comparison of the English and Chemistry departments. We note that although the departments differ greatly on our original measure of "efficiency," (.039 to .171), by the time we have added the M.A. degrees and equalized for financial support and proportion male, the gap has narrowed considerably, (.155 to .171). Equalizing financial support has accounted for an increase in the English department's dependent variable of .074, (.004 + .053 + .017), raising the department's performance from .039 to .113 Ph.D.'s per student year. We conclude that Stark's strong statement, "Equal support will produce equal results," is not true; approximately equal performance will be achieved only by equalizing the proportion of male students and by crediting the department with one Ph.D. for every five terminal M.A.'s awarded.

TABLE IV

COMPARISON OF ENGLISH AND CHEMISTRY DEPARTMENTS*

	ENGLISH	CHEMISTRY
Average annual Ph.D. production	18	50
Average terminal M.A. production	68	2
Average graduate enrollment	450	295
Dependent variable: $\frac{PhD}{GREN}$	18/450 = .039	50/295 = .170
Add: $\hat{\beta}_1 \frac{MA}{GREN}$	$\frac{(.201)(68)}{450}$ = .030	$\frac{(.201)(2)}{295}$ = .001
$\frac{NUMTA}{GREN}$	.189	.275
Add: $\hat{\beta}_3 \frac{NUMTA}{GREN}$	(.049)(.275 - .189) = .004	
$\frac{NUMRA}{GREN}$	.044	.445
Add: $\hat{\beta}_4 \frac{NUMRA}{GREN}$	(.131)(.445 - .044) = .053	
$\frac{NUMAW}{GREN}$	.101	.279
Add: $\hat{\beta}_5 \frac{NUMAW}{GREN}$	(.097)(.279 - .101) = .017	
$\frac{NUMALE}{GREN}$	.61	.87
Add: $\hat{\beta}_8 \frac{NUMALE}{GREN}$	(.048)(.87 - .61) = .012	
Sum →	.155	.171

*Based on parameter estimates from regression equation 4, Table II. The two departments do not differ on faculty-graduate student ratios or on Cartter ratings.

Adherents of the production function approach do encounter another major problem when they assert the effectiveness of financial support in raising the performance of humanities departments to the level of physical science departments. This arises when we note in our regression results that research assistantships have the greatest estimated impact on Ph.D. production. In our example with the English department, the major factor in improving performance was the hypothetical increase in English R.A. positions from 4.4% to 44.5% of the graduate enrollment. Here we confront the issue of technology; is it reasonable to think that the English department could utilize large numbers of research assistantships in the same effective manner as does the Chemistry department? The problem-oriented research group found in Chemistry has not been the model for the humanities where research remains the lonely task of the individual scholar in the library. If the English department could not effectively utilize the research assistantship, then 100% funding of graduate English students would require heavy use of fellowships and teaching assistantships, less effective ways of financing graduate study. If the large increase in R.A. positions for the English department were split equally between fellowships and T.A. assignments, the estimated impact of 100% funding would be reduced from .074 to .051 additional Ph.D.'s per student year. The composite estimate for the English department would be reduced from .155 to .132 Ph.D.'s per student year, a figure representing an input of nearly two more student years per degree than in Chemistry.

Relation of the Ph.D. Production Function to the Theory of Departmental Behavior

A considerable effort has been made in this report to examine an hypothesis differing from that proposed in the theory of departmental behavior. This approach was dictated by two considerations. First, the alternative hypothesis, with its implied Ph.D. production function, represents the dominant view, and yet that theory has not previously been systematically explored. Secondly, in presenting a market-oriented theory, it seemed essential to confront the production function approach head-on, for fear that our theory would be dismissed by a critic's simply pointing to the greater financial support available in certain disciplines. In order to answer such casual empiricism, it was necessary to estimate as precisely as possible the impact of financial support variables.

Further motivation underlay the work of this report, however. Our theory differs from the production function approach not by denying the importance of financial support, but by denying that these variables can truly be considered exogenous. We would argue that fields such as chemistry and physics have been more highly endowed with financial support than the humanities because of the greater demand for chemists and physicists than for philosophers. National policy regarding the need to train scientific manpower led naturally to the influx of federal money in the form of NSF, NDEA, and NIH fellowships and grants to support graduate students in the high demand fields. One might even conjecture that these federal grants would have been withdrawn from any Berkeley department that failed to produce Ph.D.'s in response to the funding. The relationships between demand, financial support, and enrollments will be developed in greater detail in the next chapter.

Consequently, in examining estimates of the Ph.D. production function, our theory would interpret fellowships and research assistantships as endogenous variables of a larger supply and demand system for Ph.D.'s. (By contrast, teaching assistantships are not proxies for external demand, but represent the university's internal demand for instructional support.) On this interpretation, we question whether a large increase in financial support unaccompanied by growing market demand would have the effect that our production function estimates might lead us to expect. The final outcome of the Ford Foundation Career Fellowship program should provide evidence bearing on these conflicting hypotheses.

ERIC

III. SUPPLY AND DEMAND FOR Ph.D.'s

A. An Index of Excess Demand and the Relation to Financial Support Variables.

This section will briefly discuss the literature on the supply and demand for Ph.D.'s, culminating in a shortage ranking for the 28 disciplines. Using this ranking, we shall examine the relation of fellowships, teaching assistantships, and research assistantships to graduate enrollment and to demand; simple regression techniques will be used to illustrate the causal connections between these variables.

Writing in 1966, Allan Cartter made the following observations:

> Considering the importance of the problem to higher education, and the many hundreds of millions of dollars appropriated by the federal government for the expansion of graduate education over the last few years, it is rather astonishing that we know so little about the present and probable supply and demand of college teachers.[9]

Cartter was referring to our ignorance regarding aggregate supply and demand for Ph.D.'s; he later comments that we know even less about supply and demand by field.[10] Consequently, the reader should be alerted to the lack of good data in this critical area.

The recent history of this subject begins in 1955 with the first of a biennial series published by the National Education Association (NEA), entitled, "Teacher Supply and Demand in Universities, Colleges, and Junior

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[9] Allan Cartter, "The Supply of and Demand for College Teachers," Journal of Human Resources, Summer 1966, p. 22.

[10] Ibid., p. 38.

Colleges."[11] These reports surveyed the majority of colleges and universities in the country to determine which fields were experiencing critical manpower shortages; the NEA research staff then developed a forecasting model which was published in the 1961 report,[12] along with predictions of the number of new Ph.D.'s needed annually to 1970. The model predicted growing shortages of Ph.D.'s and a concomitant deterioration of faculty quality. Cartter comments on the mood engendered by these reports:

> Over the last few years, various distinguished educational spokesmen have used such terms as "disastrous shortage," "serious crisis," the nation standing "virtually paralyzed," "frightening figures," and "a major national scandal" to describe the supply of college teachers and have called for "heroic efforts," "crash programs," and new degrees short of the doctorate to stem the tide.[13]

By the middle 1960's, Cartter observed that the dire predictions were not coming true; rather than dropping sharply, the proportion of Ph.D.'s on most college faculties was actually rising. Upon closer examination, he detected several erroneous assumptions in the NEA forecasting model, corrected them, and redid the predictions.[14] The results of his forecasting are reproduced in Figure 2. To illustrate the range of disagreement on this

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[11] National Education Association, "Teacher Supply and Demand in Degree Granting Institutions, 1954-55," Washington, D.C., 1955; National Education Association, "Teacher Supply and Demand in Colleges and Universities, Washington Universities, Colleges, and Junior Colleges, 1957-58 and 1958-59," (and bienially thereafter through 1963-64 and 1964-65), Washington, D.C., 1959,1961, 1963, 1965.

[12] National Education Association, "Teacher Supply and Demand in Universities, Colleges, and Junior Colleges, 1959-60 and 1960-61," Washington, D.C., 1961, pp. 51-56.

[13] Cartter, op. cit., p. 22.

[14] Ibid.

subject, at the same time Cartter was predicting an excess supply of Ph.D.'s beginning in 1969, an Office of Education study published in 1964 was predicting a cumulative deficit of 121,700 faculty members with the doctorate by 1974.[15] Evidence from the 1969-70 professional meetings suggests that Cartter's forecast was the more correct.

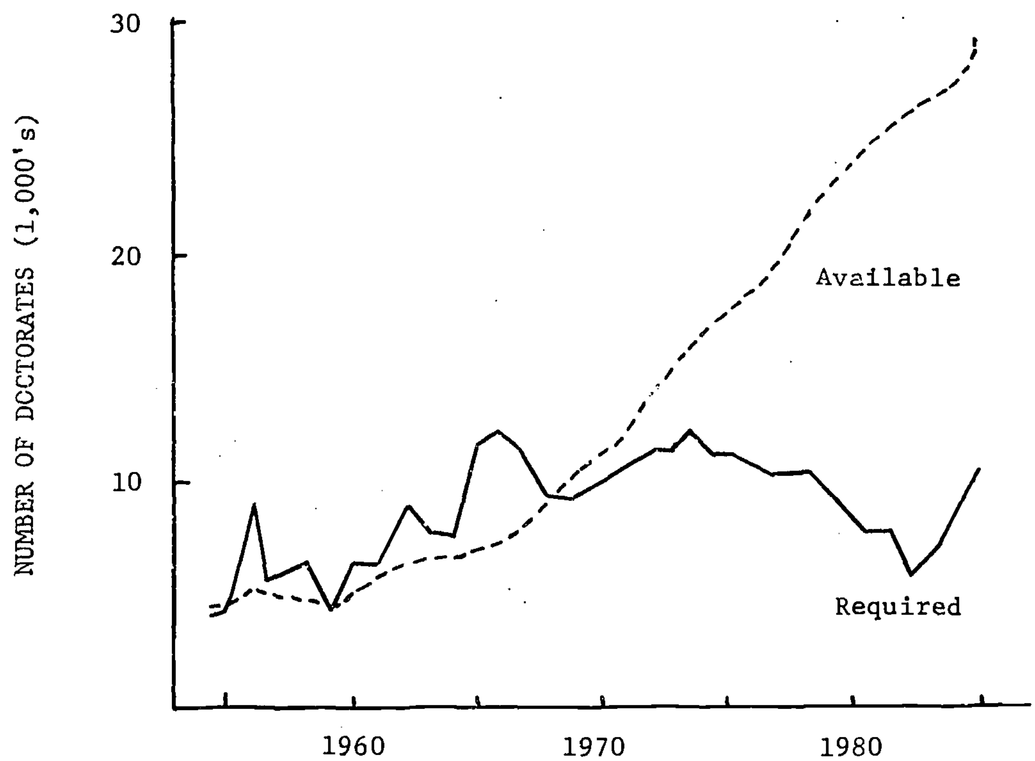

Figure 2

Doctorates Available and Doctorates Required to Maintain Constant Quality of Faculty at 1963/64 Level*

*Source: Cartter, "The Supply of and Demand for College Teachers," Journal of Human Resources, Summer 1966, p. 35.

So much for the aggregate supply-demand picture; what can we say about this balance within disciplines? Apart from the NEA surveys, the

[15] Cartter, "The Economics of Higher Education," Contemporary Economic Issues, ed. Neil W. Chamberlain, Richard D. Irwin, 1969, p. 167.

only[16] published data we have found is presented by David Brown in a 1965 study, Academic Labor Markets,[17] prepared for the U.S. Department of Labor. In Chapter 5, Brown discusses the manpower shortage by discipline, and proposes several measures for comparing excess demands across fields:[18]

(1) Starting salaries of newly graduated Ph.D.'s;
(2) Extent of salary increase;
(3) Salaries paid to full professors in 1962-63;
(4) Academic rank of newly graduated Ph.D.'s;
(5) Unfilled positions as a percentage of all positions;
(6) Percentage of newly graduated Ph.D.'s entering college teaching;
(7) Expansion demand as a percentage of all hiring.

Brown argues that none of the above measures taken separately adequately captures the relative supply-demand balance across fields; however, survey data Brown collected allowed him to rank 23 disciplines on each of the seven measures. These separate rankings were then combined into a single shortage index, reproduced as Table V. In commenting on these rankings, Brown stresses that, "The individual discipline markets are tighter in the expanding fields and in those fields where the opportunities outside the academic community are greatest."[19]

Brown's index includes 16 of the 28 fields considered in the present study. In order to integrate the other 12 disciplines within his list, the following procedure was utilized:

(1) Using data from the National Academy of Sciences,[20] the 28 fields were ranked according to the percentage of new Ph.D.'s entering college teaching. In agreement with Brown, it was

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[16]Richard Freeman, "The Labor Market for College Trained Manpower," unpublished Ph.D. dissertation, Harvard University, Cambridge, Massachusetts, 1967 provides a measure of relative market disequilibrium for several scientific fields.

[17]David Brown, Academic Labor Markets, A Report to the U.S. Department of Labor, Washington, D. C., September 1965.

[18]Brown, op. cit., p. 87.

[19]Ibid., p. 92

[20]National Academy of Sciences, "Survey of Earned Doctorates," Washington, D.C. Computer tape for Berkeley graduates, 1958-67, Graduate Division, University of California, Berkeley.

TABLE V

Brown's Ranking of 23 Disciplines by Excess Demand,* 1964

Discipline	Shortage Index
Electrical Engineering	1
Educational Services and Administration	2
Mechanical Engineering	3
Mathematics	4
Physics	5
Economics	6
Civil Engineering	7
Chemistry	8
Counseling and Guidance	9
Clinical Psychology	10
Sociology	11
Art	12
Secondary Education	13
Political Science	14
Earth Sciences and Geology	15
General Biology	16
Biochemistry	17
Physical Education and Health	18
Music	19
General Zoology	20
English and Literature	21
History	22
French	23

*Rank of 1 means excess demand greatest in that discipline.

Source: David Brown, Academic Labor Markets, [1965].

assumed that the smaller the percentage entering teaching, the broader the potential market, and hence the greater the demand.

(2) The relative placement of the 16 fields from Brown's list was preserved intact.

(3) It was assumed that similar disciplines would be ranked closely together, i.e., that excess demand for French Ph.D.'s would be very close to the excess demand for Spanish or German Ph.D.'s.

(4) Brown's stress on expansion demand in the newer fields was observed. For example, Anthropology was ranked higher than the breadth of its market would suggest because it is a relatively new field and has experienced considerable expansion demand.

Following these principles, the additional 12 fields were combined with Brown's shortage index, and ranked as in Table VI. The revised shortage index is certainly subject to criticism, for it was constructed from crude data; the relative placement of particular departments might properly be adjusted upward or downward one or two positions. However, substantial improvements on this simple ranking would require a data collecting effort far beyond the scope of this study. For the simple statistical tests we wish to perform, the ranking in Table VI will suffice; results are not sensitive to marginal changes in the ordering.

The excess demand ranking in Table VI allows us to complete the analysis of the first section. At the close of that section, we suggested that fellowships and research assistantships should not be interpreted as exogenous variables, but as endogenous variables causally related to market demand, while teaching assistantships represent internal manpower demands

TABLE VI

Ranking of 28 Disciplines by Excess Demand, Integration of 12 Excluded Disciplines with Brown's Shortage Index, Table XI, 1964

Discipline	Revised Shortage Index
Electrical Engineering	1
Chemical Engineering	2
Mechanical Engineering	3
Mathematics	4
Physics	5
Economics	6
Civil Engineering	7
Entomology	8
Chemistry	9
Astronomy	10
Psychology	11
Anthropology	12
Sociology	13
Political Science	14
Geography	15
Geology	16
Bacteriology	17
Biochemistry	18
Physiology	19
Botany	20
Zoology	21
English	22
History	23
Philosophy	24
Classics	25
Spanish	26
French	27
German	28

of the university, having no connection with market demand. Departments use all three forms of aid to support graduate students, suggesting the hypothesis that enrollments may be functionally related to the number of fellowships, R.A. and T.A. positions the department controls. Consequently, departments that must rely heavily on T.A. positions to support graduate students can be expected to have enrollments larger than warranted by market demand. One would expect to find the highest attrition rates in these departments, as output is scaled to demand rather than to enrollment.

There are several plausible ways to test these assertions, each method involving a slightly different interpretation of the underlying process. One view would focus upon the <u>absolute number</u> of fellowships, teaching and research assistantships in each department, and their relationships to market demand and enrollments. The sequence suggested by this view can be expressed in the simple functional form as follows:

(1) Fellowships = f(Excess Demand)

(2) Research Assistantships = f(Excess Demand)

(3) Teaching Assistantships $\neq$ f(Excess Demand)

(4) Enrollment = g(Fellowships, Research Assistantships, Teaching Assistantships) .

Expanding the interpretation, we could add a final equation,

(5) Ph.D.'s = h(Enrollment)

if enrollments were not partially determined by T.A. positions; in the absence of this form of financial support, which is dominant in the humanities and unrelated to market demand, one might observe the following simple process at work:

Demand → (Research Assistantships / Fellowships) → Enrollment → Ph.D.'s

Figure 3

Another interpretation would focus upon the proportion of graduate students financed by fellowships, teaching and research assistantships in the various fields. It might be argued that the use of absolute numbers of stipends is misleading since Berkeley departments differ considerably in size, the differences representing, in part, decisions to emphasize particular fields over others. Consequently, this view suggests that departments ranked high in excess demand should have a large proportion of students supported on fellowships and research assistantships, while the field with less demand would be marked by a large proportion of students supported on teaching assistantships.

A third interpretation might emphasize the proportion of supported students financed by fellowships, teaching and research assistantships in each department. In other words, rather than calculating the proportion of a department's total enrollment on fellowship, etc., as in the second method, this approach excludes the non-financed students and examines the proportion of total financing available in each form. The argument underlying this approach might be the belief that in certain fields, particularly the humanities, a large number of students traditionally do not expect support and will enroll without it. Therefore, on this view, non-financed students should be excluded from the calculations, rendering the proportions more meaningful. As in the second interpretation, we expect the high demand fields to have a large proportion of financing in fellowships and research assistantships, and the low demand fields to have a large proportion of financing in teaching assistantships.

In presenting regression estimates of the relationships suggested by these three interpretations, our intention is not to discriminate between the models, but to determine whether the relationships hypothesized between demand, financial support, and enrollments are present in each of the plausible specifications. Furthermore, since our demand index is a rudimentary body of data, we place more emphasis on the sign of the coefficient than on the numerical estimates.

Table VII contains regression estimates of the first model discussed, involving absolute numbers. The revised shortage index of Table VI was used as the independent variable (XSDMD) measuring excess demand; the rank ordering was reversed numerically so that disciplines with greatest excess demand carry the largest rank numbers. We note that both the number of fellowships and the number of research assistantships are positively and significantly related to the excess demand ranking, while the number of teaching assistantships is not significantly related. However, from equation (4), we see that the number of graduate enrollments is determined with nearly equal weight by the number of fellowships and the number of teaching assistantships. Thus, on this interpretation, departments such as French and German with limited market demand for their Ph.D.'s obtain an equally limited number of fellowships; the department's demand for larger numbers of graduate students is accommodated by T.A. positions that permit an enrollment much larger than demand conditions warrant. We should hardly be surprised by the high attrition rates engendered by these conflicting forces.

TABLE VII

ESTIMATED RELATIONSHIPS BETWEEN EXCESS DEMAND, FINANCIAL SUPPORT, AND ENROLLMENT, 28 BERKELEY DEPARTMENTS*

			R^2
(1)	NUMAW[a]	= 2.94 + 1.85 XSDMD[e]	.41
		(7.30) (0.44)	
(2)	NUMRA[b]	= -12.16 + 2.82 XSDMD	.48
		(9.62) (0.58)	
(3)	NUMTA[c]	= 21.97 + 0.21 XSDMD	.008
		(7.58) (0.46)	
(4)	NUMGRAD[d]	= -0.71 + 2.42 NUMAW + 0.02 NUMRA + 2.32 NUMTA	.85
		(13.90) (0.50) (0.36) (0.48)	

[a]NUMAW = number of fellowships over $2,000

[b]NUMRA = number of research assistantships

[c]NUMTA = number of teaching assistantships

[d]NUMGRAD = number of graduate enrollments

[e]XSDMD = reverse numerical rank ordering of the revised shortage index, Table VI

*Brown's Shortage Index reflects the supply-demand balance of 1964, while the Berkeley financial support data was collected in 1966-67, introducing a 2-3 year lag. Data on financial support is the same used in the first section.

Estimates of the second model are presented in Table VIII. The signs of all estimated coefficients are as expected; a positive relationship between excess demand and the proportion of students on fellowships (equation 5) and research assistantships (equation 6), a negative relation between excess demand and the proportion supported on teaching assistantships (equation (7)). Equation (8) combines fellowships and research assistantships, demonstrating their strong positive relation to excess demand. Note in equation (9) that when teaching assistantships are added, the total proportion financed bears a positive but much weaker relation to demand.

Estimates to the third model, presented in Table IX, are also as expected, indicating that the hypothesized relationships between excess demand and financial support variables are present in all three plausible specifications of the model. In light of these results, we again raise the issue discussed at the end of the first section: will an increase in graduate student financial support that is not associated with increased market demand result in a greater output of Ph.D.'s? If the theory of departmental behavior discussed earlier is correct, an infusion of funds under such circumstances would not necessarily increase the production of Ph.D.'s. In fact, increased financial support coupled with worsening job markets might extend the student's average time in graduate school before leaving without the Ph.D., paradoxically resulting in decreased "efficiency." As mentioned in the first section, final evaluation of the Ford Foundation Career Fellowship Program will provide an important test of the theory.

TABLE VIII

Estimated Relationships Between Excess Demand and the Proportion of Graduate Students Financed, 28 Berkeley Departments*

R^2

(5) $$\frac{\text{NUMAW}^{(a)}}{\text{NUMGRAD}^{(a)}} = \underset{(0.049)}{0.183} + \underset{(0.003)}{0.004}\ \text{XSDMD}^{(a)} \qquad .06$$

(6) $$\frac{\text{NUMRA}^{(a)}}{\text{NUMGRAD}} = \underset{(0.042)}{0.006} + \underset{(0.003)}{0.013}\ \text{XSDMD} \qquad .50$$

(7) $$\frac{\text{NUMTA}^{(a)}}{\text{NUMGRAD}} = \underset{(0.043)}{0.365} - \underset{(0.003)}{0.010}\ \text{XSDMD} \qquad .37$$

(8) $$\frac{\text{NUMAW} + \text{NUMRA}}{\text{NUMGRAD}} = \underset{(0.066)}{0.189} + \underset{(0.004)}{0.017}\ \text{XSDMD} \qquad .41$$

(9) $$\frac{\text{NUMFIN}^{(b)}}{\text{NUMGRAD}} = 0.553 + 0.007\ \text{XSDMD} \qquad .11$$

[illegible]2) (0.004)

(a) Defined in Table VII

(b) NUMFIN = NUMAW + NUMRA + NUMTA

* Data the same as in Table VII.

TABLE IX

Estimated Relationships Between Excess Demand and the Proportion of Departmental Financial Support Represented by Fellowships, Teaching and Research Assistantships, 28 Berkeley Departments*

			R^2
(10)	$\frac{NUMAW^{(a)}}{NUMFIN^{(b)}} = \underset{(0.063)}{0.309} + \underset{(0.0038)}{0.004}\ XSDMD^{(a)}$		.04
(11)	$\frac{NUMRA^{(a)}}{NUMFIN} = \underset{(0.043)}{0.034} + \underset{(0.003)}{0.017}\ XSDMD$		.61
(12)	$\frac{NUMTA^{(a)}}{NUMFIN} = \underset{(0.068)}{0.657} - \underset{(0.004)}{0.021}\ XSDMD$		.49

(a) Defined in Table VII.

(b) Defined in Table VIII.

*Data the same as in Tables VII and VIII.

B. National Production of New Ph.D.'s

Although we have no precise method for determining the demand schedule for Ph.D.'s by field over time, annual figures are available on the supply of new doctorates. In assessing departmental performance, a comparison of Berkeley's doctoral output with national production of Ph.D.'s adds to the plausibility of our market determined theory.

Data were collected on doctorates awarded annually by field for the 21 year period, 1947-48 to 1967-68. In addition to total production, degrees awarded by the top 20 quality ranked schools[21] in each discipline were recorded. Table X presents the 21 year totals for each field. Examination of the column headed "Berkeley % of Top 20" demonstrates that Berkeley is not an insignificant producer in any of the subject areas. For example, Berkeley's 41 Ph.D.'s in Spanish (an average of 2 per year) still represents 6.3% of the production by the top 20 schools. In terms of sheer numbers, a recent publication of the National Research Council, Report on Doctoral Programs, shows Berkeley ranked 5th out of 184 institutions in total doctorate production for the period 1957-62, and 1st out of the 213 for the period 1963-67.[22] Of the fields considered in this study, Berkeley's lowest departmental ranking in terms of Ph.D. output for the period 1963-67 was 13th out of 102 in the English and American Language and Literature category.[23] In virtually every other field, Berkeley ranked within

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[21] National Research Council, Report on Doctoral Programs, Washington, D.C., 1968, pp. 16-17.

[22] Ibid., p. 17.

[23] Comparable figures for the remaining 23 fields are presented in the data appendix to Breneman, David W., "The Ph.D. Production Process: A Study of Departmental Behavior," unpublished Ph.D. dissertation, University of California, September 1970.

TABLE X

Total Ph.D. Degrees Produced by U.S. Universities, 28 Fields,* 1947-48 to 1967-68 (21 Year Totals)

Field	# Ph.D.'s Awarded in U.S.	# Ph.D.'s Awarded by 20 Top Quality Schools (a)	# Ph.D.'s Awarded by Berkeley	% Total Produced by Top 20 Schools	Berkeley % of Total	Berkeley % of Top 20
Classics	775	638	25	82.3	3.2	3.9
English	9161	5349	209	58.4	2.3	3.9
French	1399	1074	53	76.8	3.8	4.9
German	1021	696	53	68.2	5.2	7.6
Spanish	1036	649	41	62.6	4.0	6.3
Philosophy	2190	1381	66	63.1	3.0	4.8
Anthro.	1316	1197	119	91.0	9.0	9.9
Economics	6077	3538	300	58.2	4.9	8.5
Geography	1115	936	51	83.9	4.6	5.4
History	7910	4695	364	59.4	4.6	7.8
Poli. Sci.	4472	2839	194	63.5	4.3	6.8
Sociology	3728	2118	95	56.8	2.5	4.5
Bacteriology	3247 (b)	1286 (b)	85	39.6	2.6	6.6
Biochemistry	3857 (b)	1655 (b)	198	42.9	5.1	12.0
Botany	2947	1485	130	50.4	4.4	8.8

(continued next page)

TABLE X (Continued)

Field	#Ph.D.'s Awarded in U.S.	# Ph.D.'s Awarded by 20 Top Quality Schools (a)	# Ph.D.'s Awarded by Berkeley	% Total Produced by Top 20 Schools	Berkeley % of Total	Berkeley % of Top 20
Entomology	1710	1408	188	82.3	11.0	13.4
Physiology	1727 (b)	721 (b)	95	41.7	5.5	13.2
Psychology	14157	5448	351	38.5	2.5	6.4
Zoology	3915 (b)	1989 (b)	236	50.8	6.0	11.9
Astronomy	533	487	65	91.4	12.2	13.3
Chemistry	23418	10412	778	44.5	3.3	7.5
Geology	3542	2414	92	68.2	2.6	3.8
Mathematics	7097	3635	313	51.2	4.4	8.6
Physics	12699	6616	811	52.1	6.4	12.2
Chem. Eng.	4142	2236	103	54.0	2.5	4.6
Civil Eng.	2405	1684	142	70.0	5.9	8.4
Elec. Eng.	5617	3755	244	66.8	4.3	6.5
Mech. Eng.	2846	1760	146	61.8	5.1	8.3
Total 28 Fields	134,059	72,101	5,547	53.8%	4.1%	7.7%

*H.E.W. Publications, Earned Degrees Conferred

(a) Ranked by Cartter Report [1966]
(b) Totals are understated because certain universities did not list their degrees under this category.

the top four producers. Forgetting departmental enrollments and looking just at output, there would seem to be little cause for concern.

Shifting to individual fields, consider the supply of French Ph.D.'s reported in Table XI. Note that Berkeley's output of 2-3 Ph.D.'s per year generally accounted for 4-6% of Top 20 production. One realizes how thin the market for French Ph.D.'s is by recalling that Brown's shortage index ranked this field last in terms of excess demand during the middle 1960's; in fact, Brown referred to French as one of the surplus disciplines. And yet, during that period total production averaged only 70 Ph.D.'s per year, with the Top 20 schools averaging approximately 50 Ph.D.'s. If, during 1963-64, Berkeley's department, with a graduate enrollment of over 90 students, had produced a reasonable number of Ph.D.'s for that enrollment (say 14 instead of 4), Berkeley's percent of the Top 20 production would have risen from 6.0% to 18.2%. We submit that an increase of such magnitude would not have gone unnoticed in a very thin market. One can imagine the department facing a very difficult marketing operation; not only might the jobs not be there, but within the fraternity of French departments, such an increase might have been interpreted as a reduction in quality. The department might have found it very difficult to regain its reputation as a quality program.

Four additional Tables complete this section, covering the supply of Ph.D.'s in German, History, Political Science, and Chemistry. For those fields typified by high attrition rates at Berkeley (German, History, Political Science), the reader is encouraged to consider the effect tripling the department's output would have had upon the market in each field. We believe that these figures reveal a major determinant of each department's decision regarding the desirable number of Ph.D.'s to produce.

TABLE XI

Annual U.S. Production of Ph.D. Degrees in French,* 1947-48 to 1967-68

Year	# Ph.D.'s Awarded in U.S.	# Ph.D.'s Awarded by 20 Top Quality Schools[a]	# Ph.D.'s Awarded by Berkeley	% Total Produced by Top 20 Schools	Berkeley % of Total	Berkeley % of Top 20
1967-68	159	119	5	74.8	3.1	4.2
1966-67	118	83	5	70.2	4.2	6.0
1965-66	94	69	6	73.4	6.4	8.7
1964-65	80	57	2	71.2	2.5	3.5
1963-64	88	67	4	76.1	4.5	6.0
1962-63	63	50	3	79.4	4.8	6.0
1961-62	63	48	3	76.2	4.8	6.2
1960-61	51	35	2	68.6	3.9	5.7
1959-60	63	51	3	81.0	4.8	5.9
1958-59	70	55	3	78.6	4.3	5.4
1957-58	41	35	2	85.4	4.9	5.7
1956-57	50	43	3	86.0	6.0	7.0
1955-56	59	48	2	81.4	3.4	4.2
1954-55	53	40	2	75.5	3.8	5.0
1953-54	58	35	1	60.4	1.7	2.9

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TABLE XI (Continued)

Year	# Ph.D.'s Awarded in U.S.	# Ph.D.'s Awarded by 20 Top Quality Schools	# Ph.D.'s Awarded by Berkeley	% Total Produced by Top 20 Schools	Berkeley % of Total	Berkeley % of Top 20
1952-53	57	43	2	75.4	3.5	4.6
1951-52	52	46	2	88.5	3.8	4.3
1950-51	44	35	1	79.5	2.3	2.8
1949-50	58	51	1	87.9	1.7	2.0
1948-49	48	39	0	81.2	0.0	0.0
1947-48	30	25	1	83.3	3.3	4.0
21 Year Totals:	1399	1074	53	76.8%	3.8%	4.9%

*Source: H.E.W. Publications, Earned Degrees Conferred.

(a)Ranked by the Cartter Report [1965].

Other Statistics Based upon 21 Year Totals		
	Total U.S. Universities	Berkeley
French Degrees as % of Total Degrees Awarded in all 28 Fields	1.04%	0.95%
% Degrees in French Awarded to Men	64.8 %	81.1 %

TABLE XII

Annual U.S. Production of Ph.D. Degrees in German,* 1947-48 to 1967-68

Year	# Ph.D.'s Awarded in U.S.	# Ph.D.'s Awarded by 20 Top Quality Schools(a)	# Ph.D.'s Awarded by Berkeley	% Total Produced by Top 20 Schools	Berkeley % of Total	Berkeley % of Top 20
1967-68	122	69	4	56.6	3.3	5.8
1966-67	100	67	4	67.0	4.0	6.0
1965-66	95	49	4	51.6	4.2	8.2
1964-65	68	46	4	67.6	5.9	8.7
1963-64	78	51	2	65.4	2.6	3.9
1962-63	37	28	1	75.7	2.7	3.6
1961-62	46	34	5	73.9	10.9	14.7
1960-61	38	26	1	68.4	2.6	3.8
1959-60	24	17	0	70.8	0.0	0.0
1958-59	29	26	2	89.6	6.9	7.7
1957-58	35	27	5	77.1	14.3	18.5
1956-57	32	25	5	78.1	15.6	20.0
1955-56	33	17	3	51.5	9.1	17.6
1954-55	26	19	2	73.1	7.7	10.5
1953-54	46	35	4	76.1	8.7	11.4

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TABLE XII (Continued)

Year	# Ph.D.'s Awarded in U.S.	# Ph.D.'s Awarded by 20 Top Quality Schools[a]	# Ph.D.'s Awarded by Berkeley	% Total Produced by Top 20 Schools	Berkeley % of Total	Berkeley % of Top 20
1952-53	37	33	1	89.2	2.7	3.0
1951-52	56	43	0	76.8	0.0	0.0
1950-51	31	22	1	70.1	3.2	4.5
1949-50	40	30	3	75.0	7.5	10.0
1948-49	27	14	0	51.8	0.0	0.0
1947-48	21	18	2	85.7	9.5	11.1
21 Year Totals	1021	696	53	68.2%	5.2%	7.6%

* Source: H.E.W. Publications, Earned Degrees Conferred

(a) Ranked by the Cartter Report [1966]

Other Statistics Based Upon 21 Year Totals

	Total U.S. Universities	Berkeley
German Degrees as % of Total Degrees Awarded in all 28 Fields	0.76%	0.95%
% Degrees in German Awarded to Men	78.6 %	86.8 %

TABLE XIII

Annual U.S. Production of Ph.D. Degrees in History,* 1947-48 to 1967-68

Year	# Ph.D.'s Awarded in U.S.	# Ph.D.'s Awarded by 20 Top Quality Schools[(a)]	# Ph.D.'s Awarded by Berkeley	% Total Produced by Top 20 Schools	Berkeley % of Total	Berkeley % of Top 20
1967-68	688	327	19	47.5	2.8	5.8
1966-67	655	307	27	46.9	4.1	8.8
1965-66	599	314	29	52.4	4.8	9.2
1964-65	576	308	33	53.5	5.7	10.7
1963-64	507	296	26	58.4	5.1	8.8
1962-63	378	219	24	57.9	6.3	11.0
1961-62	343	211	19	61.5	5.5	9.0
1960-61	371	227	14	61.2	3.8	6.2
1959-60	342	221	14	64.6	4.1	6.3
1958-59	324	199	14	61.4	4.3	7.0
1957-58	297	184	7	62.0	2.4	3.8
1956-57	314	206	16	65.6	5.1	7.8
1955-56	259	165	12	63.7	4.6	7.3
1954-55	310	194	10	62.6	3.2	5.2
1953-54	355	232	9	65.4	2.5	3.9

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TABLE XIII (Continued)

Year	# Ph.D.'s Awarded in U.S.	# Ph.D.'s Awarded by 20 Top Quality Schools	# Ph.D.'s Awarded by Berkeley	% Total Produced by Top 20 Schools	Berkeley % of Total	Berkeley % of Top 20
1952-53	301	203	14	67.4	4.7	6.9
1951-52	317	230	24	72.6	7.6	10.4
1950-51	325	235	17	72.3	5.2	7.2
1949-50	275	171	13	62.2	4.7	7.6
1948-49	212	136	13	64.2	6.1	9.6
1947-48	162	110	10	67.9	6.2	9.1
21 Year Totals:	7910	4695	354	59.4%	4.6%	7.8%

*Source: H.E.W. Publications, Earned Degrees Conferred.

(a) Ranked by the Cartter Report [1965].

Other Statistics Based upon 21 Year Totals		
	Total U.S. Universities	Berkeley
History Degrees as % of Total Degrees Awarded in all 28 Fields	5.90%	6.56%
% Degrees in History Awarded to Men	89.1 %	90.9 %

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TABLE XIV

Annual U.S. Production of Ph.D. Degrees in Political Science,* 1947-48 to 1967-68

Year	# Ph.D.'s Awarded in U.S.	# Ph.D.'s Awarded by 20 Top Quality Schools (a)	# Ph.D.'s Awarded by Berkeley	% Total Produced by Top 20 Schools	Berkeley % of Total	Berkeley % of Top 20
1967-68	457	267	17	58.4	3.7	6.4
1966-67	390	213	20	54.6	5.1	9.4
1965-66	336	192	15	57.1	4.5	7.8
1964-65	304	181	16	59.5	5.3	8.8
1963-64	263	171	12	65.0	4.6	7.0
1962-63	228	134	9	59.2	3.9	6.7
1961-62	214	142	7	66.4	3.3	4.9
1960-61	217	153	10	70.5	4.6	6.5
1959-60	201	137	7	68.2	3.5	5.1
1958-59	191	118	6	61.8	3.1	5.1
1957-58	170	104	8	61.2	4.7	7.7
1956-57	156	106	8	67.9	5.1	7.5
1955-56	203	126	9	62.1	4.4	7.1
1954-55	181	114	6	63.0	3.3	5.3
1953-54	153	109	9	71.2	5.9	8.2

(continued next page)

TABLE XIV (Continued)

Year	# Ph.D.'s Awarded in U.S.	# Ph.D.'s Awarded by 20 Top Quality Schools	# Ph.D.'s Awarded by Berkeley	% Total Produced by Top 20 Schools	Berkeley % of Total	Berkeley % of Top 20
1952-53	164	114	7	69.5	4.3	6.1
1951-52	147	121	11	82.3	7.5	9.1
1950-51	152	104	6	68.4	3.9	5.8
1949-50	127	85	3	66.9	2.4	3.5
1948-49	119	75	4	63.0	3.4	5.3
1947-48	99	72	4	72.7	4.0	5.6
21 Year Totals:	4472	2839	194	63.5%	4.3%	6.8%

*Source: H.E.W. Publications, Earned Degrees Conferred.

(a)Ranked by the Cartter Report [1965].

Other Statistics Based upon 21 Year Totals		
	Total U.S. Universities	Berkeley
Poli. Science Degrees as % of Total Degrees Awarded in all 28 Fields	3.33%	3.49%
% Degrees in Poli. Sci. Awarded to Men	92.2 %	92.8 %

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TABLE XV

Annual U.S. Production of Ph.D. Degrees in Chemistry,* 1947-48 to 1967-68

Year	# Ph.D.'s Awarded in U.S.	# Ph.D.'s Awarded by 20 Top Quality Schools (a)	# Ph.D.'s Awarded by Berkeley	% Total Produced by Top 20 Schools	Berkeley % of Total	Berkeley % of Top 20
1967-68	1723	647	54	37.6	3.1	8.3
1966-67	1700	608	51	35.8	3.0	8.4
1965-66	1533	554	43	36.1	2.8	7.8
1964-65	1377	552	52	40.1	3.8	9.4
1963-64	1271	496	44	39.0	3.5	8.9
1962-63	1219	509	41	41.8	3.4	8.1
1961-62	1114	487	52	43.7	4.7	10.7
1960-61	1131	497	38	43.9	3.4	7.6
1959-60	1048	483	44	46.1	4.2	9.1
1958-59	1009	432	28	42.8	2.8	6.5
1957-58	939	442	31	47.1	3.3	7.0
1956-57	1003	457	30	45.6	3.0	6.6
1955-56	986	449	22	45.5	2.2	4.9
1954-55	1005	273	27	47.1	2.7	5.7
1953-54	1013	473	39	**46.7**	3.8	8.2

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TABLE XV (Continued)

Year	# Ph.D.'s Awarded in U.S.	# Ph.D.'s Awarded by 20 Top Quality Schools	# Ph.D.'s Awarded by Berkeley	% Total Produced by Top 20 Schools	Berkeley % of Total	Berkeley % of Top 20
1952-53	999	461	22	41.1	2.2	4.8
1951-52	1031	519	30	50.3	2.9	5.8
1950-51	1046	551	35	52.7	3.3	6.4
1949-50	953	519	35	54.5	3.7	6.7
1948-49	749	446	35	59.5	4.7	7.8
1947-48	569	357	25	62.7	4.4	7.0
21 Year Totals:	23418	10412	778	45.5%	3.3%	7.5%

*Source: H.E.W. Publications, Earned Degrees Conferred.

(a)Ranked by the Cartter Report [1966].

Other Statistics Based upon 21 Year Totals

	Total U.S. Universities	Berkeley
Chemistry Degrees as % of Total Degrees Awarded in all 28 Fields	17.46%	14.02%
% Degrees in Chemistry Awarded to Men	94.4 %	94.1 %

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